Impact of nitrogen uptake on field water balance in fertirrigated melon

M.T. Castellanos, M.C. Cartagena, F. Ribas, M.J. Cabello, A. Arce, A.M. Tarquis

ABSTRACT

Agronomic management in Ciudad Real, a province in central Spain, is characteristic of semi-arid cropped areas whose water supplies have high nitrate (NO_3^-) content due to environmental degradation. This situation is aggravated by the existence of a restrictive subsurface layer of "caliche" or hardpan at a depth of 0.60 m. Under these circumstances, fertirrigation rates, including nitrogen (N) fertilizer schedules, must be carefully calibrated to optimize melon yields while minimizing the N pollution and water supply.

Such optimization was sought by fertilizing with different doses of N and irrigating at 100% of the *ETc* (crop evapotranspiration), adjusted for this crop and area. The N content in the four fertilizer doses used was: 0, 55, 82 and 109 kg N ha^{-1}. Due to the NO_3^- content in the irrigation water, however, the actual N content was 30 kg ha^{-1} higher in all four treatments repeated in two different years.

The results showed correlation between melon plant N uptake and drainage (*Dr*), which in turn affects the amount of N leached, as well as correlation between *Dr* and *LAI* (leaf area index) for each treatment. A fertilizer factor (α) was estimated through two methods, from difference in *Dr* and in *LAI* ratio with respect to the maximum N dose, to correct *ETc* based on N doses. The difference was found in the adjusted evapotranspiration in both years using the corresponding α achieved 42–49 mm at vegetative period, depending on the method, and it was not significant at senescent period. Finally, a growth curve between N uptake and plant dry weight (*DW*) for each treatment was defined to confirm that the observed higher plant vigour, showing higher *LAI* and reduced *Dr*, was due mainly to higher N doses.

1. Introduction

The aim of best management practice (BMP) in much of the cropped, irrigated and fertirrigated farmland in Spain is to prevent fresh water and ground water contamination. The objective of BMP is to fertilize rationally at rates that minimize the environmental impact of N while maximizing crop yield (Bilbao et al., 2004; Derby et al., 2005). Traditional agronomic practices for melon in the Spanish province of Ciudad Real (Fig. 1), where these plantations account for 31% of the national area dedicated to this crop (M.A.R.M., 2009), are being increasingly replaced by fertirrigation (Rincón, 1997; Ortega et al., 2003). One traditional technique common in melon and other fruit crops in this area is plastic mulching. Among several benefits of plastic mulches is their ability to hold moisture in the soil by reducing evaporation (Lovelli et al., 2005). With lower evaporation, transpiration rises because both sensible heat and radiative heat are transferred from the surface of the plastic cover to the adjacent vegetation (Lovelli et al., 2005).

Since the adoption of Directive 91/676/EEC concerning the protection of waters against pollution caused by NO_3^- from agricultural sources, the regional government of Castile-La Mancha enacted Resolution 101/7 of 7 July 1998 (*Official Journal of Castile-La Mancha* No. 38 of 31 August 1998) protecting two hydrological units (UH) in Ciudad Real: UH.04.04, Mancha Occidental, and UH.04.06, Campo de Montiel. Melon is grown in the area around both (Castellanos et al., 2007).

Recent research on melon irrigation in the region has focused on farmers' needs, seeking solutions for water supply, irrigation systems (Ribas et al., 1995) and uniform and efficient water distribution (Ortega et al., 2003). The high salt content in irrigation water, however, necessitates the use of higher volumes of water to flush out the so-called leach fraction or salt deposited in the soil, primarily by drip systems. Failure to take these measures leads to higher salinity around the roots, reducing the osmotic, hydraulic and

Fig. 1. Location map of Ciudad Real in Spain.

leaf turgidity potential and thereby limiting photosynthesis-driven developments (Chartzoulakis, 1994; Nakamura et al., 2004). Water required for this purpose depends on the salt concentration and crop tolerance (Ayers and Westcott, 1985). Melon is moderately sensitive to salinity (100% crop loss where electric conductivity (EC) > 16 dS m^{-1}) (Ayers and Westcott, 1985).

Despite the major role played by melon farming in the area, little information is available about the effect of nitrogen (N) fertilizer on crop development. The applied fertilization doses are highly subjective (Rincón, 1997), in fact, large amounts of N are used by growers (sometimes higher than 250 kg ha^{-1}) (Castellanos et al., 2010). Over-fertilization results in NO_3^- leaching, with a high likelihood of aquifer contamination (Bawatharani et al., 2004; Flores et al., 2005; Oenema et al., 2005) and a rising NO_3^- concentration in the soil (Poch et al., 2005). In the area studied, the soil runs no deeper than 0.60 m and semi-arid conditions prevail during the growing season, adding to the complexity of the situation.

As in other regions (Moreno et al., 1996; Eilers et al., 2007), good water and fertilization management are high priorities and of particular importance in the intercrop period when soil NO_3^- is leached by precipitation, lowering the NO_3^-–N available to the next season's crop, and raising the concentration of this ion in ground water (Cartagena et al., 1995; Casey et al., 2002). The aquifers in question are the main source of the population's water supply (Miner-Moptma, 1994; M.A.R.M., 2009) and high NO_3^- content has been related to human health problems (Niaz et al., 2004).

An efficient irrigation scheduling that computes irrigation water requirements on the basis of actual evapotranspiration (*ETa*) has been widely used in both extensive and horticultural farming (Brown et al., 2001). *ETa* values are usually determined by multiplying the reference ET (*ETo*), based on meteorological data, by a correction factor known as the crop coefficient (*Kc*). The *Kc* used in this study was obtained from earlier experiments for melon grown in the same area in accordance with local agronomic practice (Ribas et al., 1995), i.e., with fairly high doses of N, applying 90 kg ha^{-1} of N fertilizer plus N applied with the irrigation water (around 100 kg ha^{-1} of N). The lower the soil fertility, the lower is the water demand due to a decline in crop biomass and consequently in leaf area index (*LAI*). This has been reported for several crops such as tobacco (Miller et al., 1967), tropical rice (Fagade and De Datta, 1971), wheat (Khalifa, 1973), peanut (Selamat and Gardner, 1985), corn (Flesch and Dale, 1988) and melon (Kirnak et al., 2005) among others. In this study, this should be reflected in *ETa* values by applying what might be called a fertilizer factor (α).

The primary aim of the present study was to quantify melon crop behaviour in terms of ET at different levels of N fertilization in this area. Based on drainage (*Dr*) estimations and the *LAI* for each treatment a fertilizer factor (α) was calculated to correct the initial melon crop coefficient (*Kc*) to estimate the ET. This was demonstrated by the relationship observed between the increase in N uptake and the corresponding increase in dry plant weight. While the existing literature reports on how the N rate and timing affect different aspects of the N cycle (N uptake, mineral N, volatilization and denitrification loss) (Sainz Rozas et al., 1999, 2001), very few information has been forthcoming for the effects of different N levels on crop water use.

2. Material and methods

2.1. Site

The experiments were conducted at the *La Entresierra* field station, Ciudad Real, in central Spain (3°56′ W; 39°0′ N; latitude of 640 m) during the May to September seasons of 2004 and 2005. Most (about 90%) of the area is nearly flat with very permeable soils overlying a petrocalcic horizon. Fissures in this horizon enhance vertical permeability locally. The area has a continental, Mediterranean climate, with widely fluctuating daily temperatures. The climatic data during the melon growing season given in Table 1 show that the summer mean temperature was over 22 °C. The cumulative precipitation during the melon growing season (May to September) ranges from 17 to 40 mm in the data registered. The driest season is the summer, which accounts for only 10% of the yearly precipitation; the rest of rainfall is recorded in autumn, winter and spring, in descending order. The thin calcareous soils in this nearly flat region, with a slope of less than 2%, lie over limestone bedrock, with an indurated caliche or hardpan (Petrocalcic Calcixerepts) subsoil at a depth of about 0.60 m.

The soil characteristics are provided in Table 2. The initial mineral N content (average of all treatments) was around 81 ± 8 kg ha^{-1} in 2004 and 88 ± 5 kg ha^{-1} in 2005 (within a depth of 0–35 cm soil). All these characteristics must be taken into account when calibrating for fertirrigation, including N fertilization rates, to optimize melon yields while minimizing the risk of N pollution of the water supply.

The soil in Fig. 2, classified in the USDA system (Soil Survey Staff, 2010) as Petrocalcic Palexeralfs, exhibits scant variability in the top 60 cm. Its genetic horizons are: Ap (0–0.3 m), Btk (0.3–0.6 m), Ckm (0.6–1.0 m), Cck (1.0 to >1.5 m). Root growth and the presence of water are therefore restricted to the top 0.60 m.

The volumetric water content for the first 0.3 m was 22.8% at field capacity (soil matric potential of −0.03 MPa) and 12.1% at wilting point (soil matric potential of −1.5 MPa) and from 0.3 to 0.7 m it was 43.0 and 21.1%, respectively.

2.2. Field experiment

In the 3 years prior to the experiment, non-irrigated winter wheat was grown on the plots, to which no organic matter or fertilizers were added. A randomized complete block design was used, with the same four N doses in 2004 and 2005, and with four replicates of each treatment. Sixteen 10.5-m × 12-m plots were selected (Fig. 3). Each plot had seven rows with eight plants in each row. On 28 May 2004 and 26 May 2005 cv. *Sancho* hybrid *Piel de sapo* melon was transplanted to the drip-irrigated plots in plastic mulch at a density of 4444 plants ha^{-1} (1.5 m × 1.5 m) (Fig. 3). The crop was harvested weekly, when there was a significant number of ripe fruit in the field, from 65 to 108 days after transplanting (DAT) in 2004 and from 68 to 110 DAT in 2005. At each harvest, melon

Table 1
The monthly and growing season climatic data of the experimental area for each year.

Climatic parameters	May	June	July	August	September
Growing season (2004)					
Minimum air temperature (°C)	10.5	13.7	16.1	13.4	10.2
Maximum air temperature (°C)	25.6	31.4	33.0	30.8	29.5
Average temperature (°C)	18.0	23.2	25.1	22.5	20.0
Rainfall (mm)	21.9	13.1	2.9	2.4	–
Relative humidity (%)	66.1	44.4	39.3	46.1	40.1
Wind speed (m s^{-1})	1.7	1.8	1.7	1.7	1.3
Growing season (2005)					
Minimum air temperature (°C)	9.3	14.5	15.3	14.5	10.7
Maximum air temperature (°C)	25.6	32.6	34.6	33.9	27.8
Average temperature (°C)	17.9	23.9	25.7	24.7	19.6
Rainfall (mm)	5.3	10.2	–	–	1.6
Relative humidity (%)	45.3	41.5	34.9	41.2	44.6
Wind speed (m s^{-1})	1.9	1.9	1.8	1.7	1.9

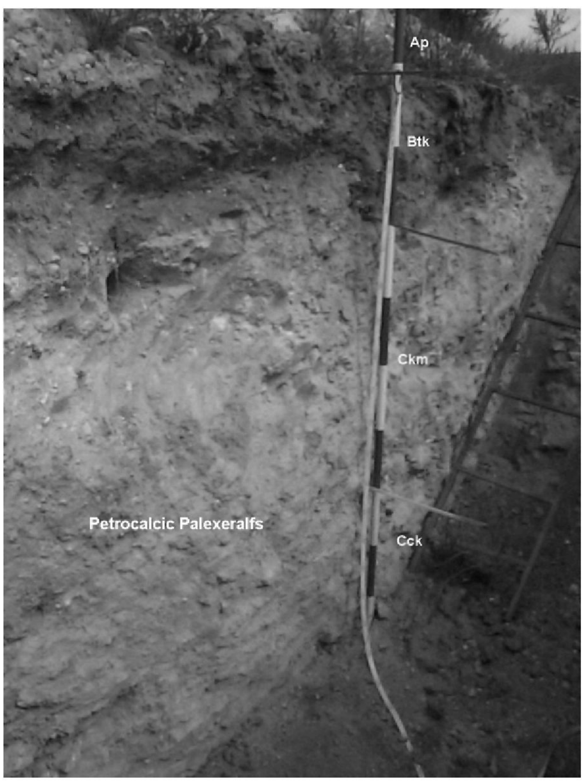

Fig. 2. Representative vertical cut of the soil at "La Entresierra" experimental field. The horizons include: Ap (0–0.3 m), Bck (0.3–0.6 m), Ckm (0.6–1.0 m), Cck (1.0 to >1.5 m). The last horizon is the petrocalcic layer characteristic of this area.

fruits were weighed individually and the total fruit yield (*FY*) was calculated.

Recommendations of N doses for this type of melon in field conditions based on scientific information do not exist. The maximum of fertilizer doses, given by the Administration, are 110 or 135 kg ha^{-1}, because melon is cultivated in vulnerable zones in the centre of Spain, according to the zone of application. So, in order to apply this dose as the maximum amount of N, four N doses (including the control) were applied in the form of ammonium nitrate during 10 weeks of the crop cycle (from June to August), from a single well at the bottom of the field where irrigation water was mixed with the respective doses of N. The total N doses were 30 (*A0*), 85 (*A1*), 112 (*A2*) and 139 (*A3*) kg N ha^{-1}. Treatment *A0*

Table 2
The physicochemical properties of the soil at the field experimental sites in 2005, 2006, and 2007.

Property	2004	2005
pH	7.9	7.9
EC (mS cm^{-1})	0.2	0.2
Organic matter (g kg^{-1})	22.3	22.6
Available P (mg kg^{-1})	18.5	19.4
Available K (mg kg^{-1})	370.6	398.9
Available Ca (mg kg^{-1})	2250.0	2302.1
Available Mg (mg kg^{-1})	821.1	815.1
N (Kjeldahl) (g kg^{-1})	1.2	1.2

Note: EC is electrical conductivity.

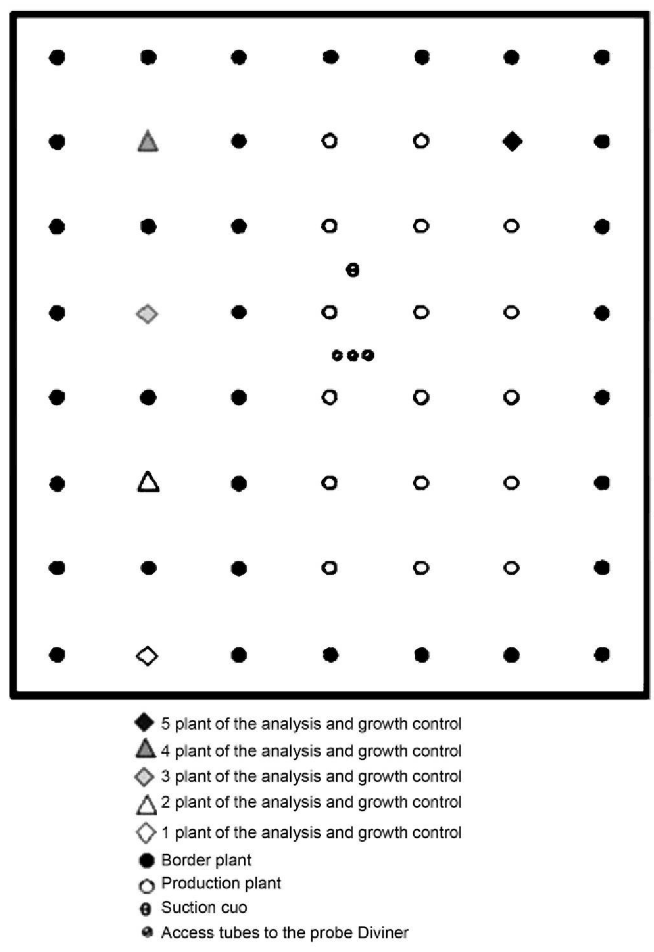

Fig. 3. Experimental plot used in the study of 126 m^2 and 4444 plant ha^{-1} plant density. Scheme of the sample design for plant N analysis, plant growth and crop yield during melon crop season. Each plot had one suction cup and three FDR (frequency domain reflectometry) probes.

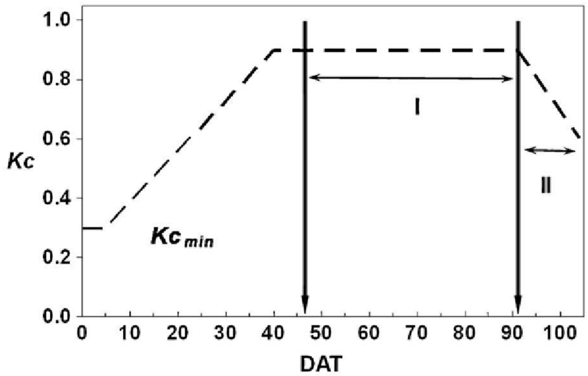

Fig. 4. Crop melon coefficient (*Kc*) under transparent plastic mulch and fertirrigation during crop season. Red arrows indicate the two periods where different treatments show different behaviour. Kc_{min} is indicated in the figure at the first crop stage when it is mainly due to evaporation. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

had no N from the fertilizer, although the irrigation water did carry some N. In the present case, the water was drawn from surface springs for both years. Water quality was chemically analyzed on a weekly basis to determine the N load (30 kg N ha^{-1}), in the form of N compounds, in the irrigation water reaching the plants.

Each row was drip-irrigated from a line with emitters spaced at 0.5 m, where these dripped water at a rate of 2 L h^{-1}. All treatments received 120 kg of phosphorus fertilizer (phosphoric acid) for the season, added to the irrigation water and injected daily, from three weeks after transplanting until the last week of August. The usual disease- and insect-control programme was implemented throughout the growing period in accordance with standard management practice to ensure that the response to N fertilizers would not be masked by other factors.

2.3. Irrigation schedule

The fields were given a 30-mm watering to help plantlets take root. After 11 June in 2004 and 7 June in 2005 and throughout the growth period, the crop was watered once a day, supplying 100% of estimated crop evapotranspiration, (*ETc*), which was calculated daily (using the FAO method, Doorenbos and Pruitt, 1977), as:

$$ETc = Kc \times ETo \tag{1}$$

where *ETo* is the reference evapotranspiration value found with the FAO Penman-Monteith method (Allen et al., 2002).

The *Kc* used was the value found in earlier years for melon grown in the same area (Ribas et al., 1995) for the N doses used by local farmers (see Fig. 4). Daily irrigation rates were the same for all plots in both years. The irrigation rate was calculated as the ratio between the *ETc* of the previous week and the efficiency of the system estimated at 0.81 (Rincón and Giménez, 1989), and the result was divided by the number of days to obtain the daily irrigation.

Since irrigation water has a high salt content, a leach fraction is needed to prevent the high salinity from affecting the crop. The water demand for this purpose depends on salt concentration and crop tolerance. Even with the irrigation water used in this study, for an average between 2 years of experimentation, which had a pH of 7.8, an EC_w of 2.0 dS m^{-1} and contained (in ppm) 5.6 NO_3^-, 0.1 NH_4^+, 192.6 Ca^{2+}, 16.2 Mg^{2+}, 162.0 Na^+, 1.4 K^+, 782.5 SO_4^{2-}, 239.1 Cl^-, irrigation (*Irr*) had to be increased by about 20% for the leach fraction and to ensure irrigation system efficiency.

2.4. Drainage

Drainage was determined at various distances from the drip line to take into account heterogeneity. Three probes were placed between two consecutive plants in the centre of each plot to measure the volumetric soil water content (θ_v) weekly, in cross-sections at 0.125, 0.375 and 0.625 cm from the drip line. Diviner frequency domain reflectometry (FDR) sensors were used to measure θ_v at 10-cm intervals in all the probes, to a depth of 0.60 m.

Drainage was calculated from the water balance equation (Doorenbos and Kassam, 1988), weekly for each treatment and throughout the period of schedule irrigation:

$$Dr = Irr + P - ETc - Rf \pm \Delta\theta_v \tag{2}$$

where *Dr* is drainage water, *Irr* the irrigation water supplied during the growth period, *P* the effective rainfall during the growth period, *ETc* evapotranspiration, *Rf* runoff, and $\Delta\theta_v$ the variation in the volumetric soil water content. The *Rf* was assumed to be negligible.

Since there was no precipitation on the dates *Dr* was compared, total irrigation could be approximately calculated as $Irr = 1.2 \times ETc$, from which it was deduced that *Dr* would be of at least this magnitude. In as much as *Kc* was calculated for treatment *A3* only, which is the usual applied dose by the growers, the following relationships hold:

$$Dr[A3] \approx 0.2 \times ETc \tag{3}$$

where *Dr*[*A*3] is the estimated drainage for treatment *A3*, the one that applies the maximum N dose (139 kg N ha^{-1}). The difference between *Dr*[*A*3] and the drainage for the rest of the treatments *Ai*(*Dr*[*A*3]) is mainly due to the real evapotranspiration considering the crop scenario under the N dose applied (*ETa*):

$$Dr[Ai] - Dr[A3] = ETa[A3] - ETa[Ai] \approx ETc - (\alpha \times ETc) \tag{4}$$

where α is the fertilizer factor that adjusts *ETc* for the effect of N dose applied to the crop. In our case, the value of α will not exceed one. Then, we obtain:

$$Dr[Ai] - Dr[A3] = (1 - \alpha) \times ETc \tag{5}$$

Based on drainage estimations we found α from following the relation:

$$\alpha = 1 - \left(\frac{Dr[Ai] - Dr[A3]}{ETc}\right) \tag{6}$$

Eq. (6) was used to estimate α in the interval when irrigation needs are highest due to a maximum *Kc* value, taking into account the phenological state of the crop. *ETa* was then estimated from the following expression:

$$ETa = \alpha \times ETc = \alpha \times (Kc \times ETo) = Ka \times ETo \tag{7}$$

$$Ka = \alpha \times Kc \tag{8}$$

where *ETo* is the crop's reference evapotranspiration.

Analysis of variance showed that the position of the probes had no significant effect on *Dr*, which was therefore calculated as the mean of the three values. These calculations were performed weekly and then summed to find the cumulative value (Castellanos et al., 2007).

2.5. Evapotranspiration

Lower N doses entail less vigorous crops and lower transpiration. Differences should consequently be expected in *ET* in agreement with Kirnak et al. (2005), who observed that the evapotranspiration (*ET*) increased with higher N levels, ranging between

138 and 160 cm in treatments with 0 and 120 kg ha^{-1} of N, respectively, in a study with melon. In as much as the irrigation schedule was based on the *Kc* for treatment *A3*, *ET* was expected to be lower in the other treatments. To obviate the need to estimate the water balance, *ETa* can be estimated by comparing the *LAI* for treatment *A3* plants (*LAI*[*A3*]) with the *LAI* for the other treatments. For melon, which has a *LAI* < 3 in nearly all phenological states, *Ka* can be expressed as (Allen et al., 2002):

$$Ka(LAI) = Kc_{\min} + (Kc_{\max} - Kc_{\min}) \times (1 - e^{-0.7LAI}) \quad (9)$$

where Kc_m is the minimum *Kc*, i.e., where *ET* is predominantly evaporative, $Kc_{\max}$ is the maximum *Kc*, i.e., where transpiration accounts for most of the *Kc*, and *LAI* is the crop leaf area index at any given time. While the second term depends on *LAI*, the first is constant for all treatments ($Kc_{\min}$ = 0.3, see Fig. 4). Since the mid-season value found for treatment *A3* was *Ka* = *Kc* = 0.90 being the maximum value ($Kc_{\max}$ = 0.90, see Fig. 4), the difference ($Kc_{\max} - Kc_{\min}$ = 0.6), is attributable to leaf transpiration for treatment *A3*. To minimize error, *Ka* can be expressed as:

$$Ka(LAI) = 0.3 + 0.6 \times \left(\frac{1 - e^{-0.7LAI[Ai]}}{1 - e^{-0.7LAI[A3]}} \right) \quad (10)$$

where *LAI*[*Ai*] is the leaf area index for treatment *Ai*. In case of *i* = 3 the fraction will give one and *Ka* = 0.90 = *Kc*. Considering Eq. (8), we can calculate α based on *LAI*[*Ai*] as the ratio between *Ka*(*LAI*) and *Kc*.

LAI was estimated from the 15th to the 91st day after transplantation (DAT) at approximately 20-day intervals, for a total of five values for 2004 and 2005. Total leaf area was measured on each sampling date with a leaf area metre (LI-3100, LI-COR, Lincoln, NE) and the result was divided by the unit ground area to find the *LAI*. Initially, all stalks were considered for the calculations, but when this became difficult in more developed plants, 500 g of representative, photosynthetically active leaves were selected and measured. The *LAI* estimated for each date and treatment was based on four replicates.

2.6. Plant analysis

To confirm that the observed higher plant vigour (showing higher LAI) was due mainly to higher N doses, the relation between the increase in dry weight (*DW*) and N uptake should be studied. Every 15–19 days during the growth period, four whole melon plants per fertilizer treatment were collected. The sampling dates were scheduled to concur with the beginning of each phenological stage: vegetative growth, reproductive growth, ripening and harvest. An additional measurement was taken after harvesting, making a total of five measurements on 15-, 34-, 53-, 70- and 91-DAT samples. A total of 80 whole plants, chosen to avoid border effects, were sampled each year. Where melon fruit was present, it was included in the measurements. Leaves, petioles, steams and fruit were separated and weighted to obtain the dry weight after the various above ground plant parts were oven-dried at 80 °C to a constant weight. The dry weight (*DW*) of the melon plant was determined as the sum of the dry weights of the above ground plant organs.

Sub-samples of the oven-dried, aboveground plant organs (leaves, petioles, steams and fruits) were ground to a fine powder to determine the N content, using the Kjeldahl method (Association of Official Analytical Chemists, AOAC, 1990). The N uptake in every organ was obtained as the product of N concentration and biomass. The N uptake of the melon plant was determined as the sum of the N uptakes of every aboveground organ of the plant.

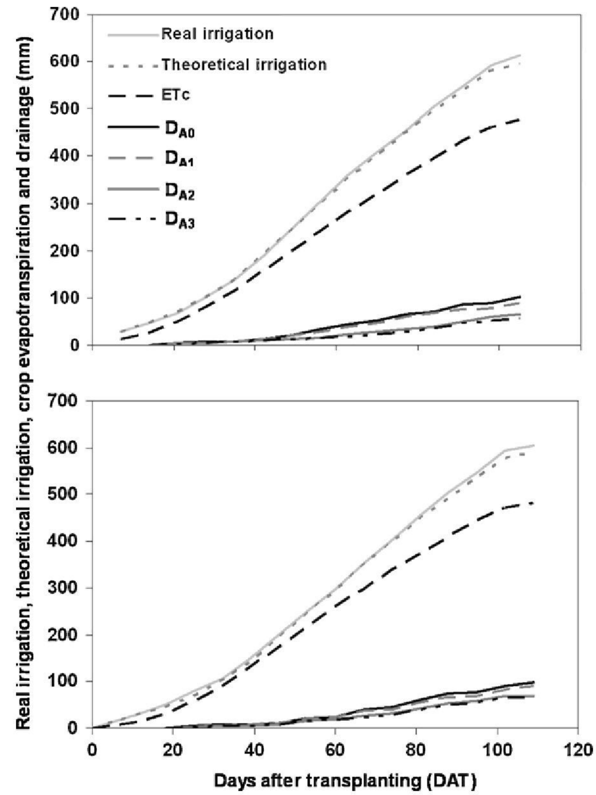

Fig. 5. Cumulative crop evapotranspiration (*ETc*), theorical irrigation, real irrigation and drainage for each N treatment in 2004 (A) and 2005 (B).

2.7. Statistical analysis

The data were analyzed statistically for each year using ANOVA. Tukey's test was applied: treatment effects were considered significant at $p \leq 0.05$. Linear and quadratic regressions were performed using the SPSS statistical analysis software.

3. Results and discussion

3.1. Drainage

Melon irrigation demand (*ETc*) during the season came to a total of 478.2 mm in 2004 and 472.8 mm in 2005, whereas actual irrigation amounted to 582.4 mm in 2004 and 574.2 mm in 2005. As Fig. 5 shows, the values of *ETc* and *Irr* were not exactly the same due to the leach fraction (lf) needed to reduce soil salt content, and the water required to ensure system efficiency. This meant that there was a continuous drainage.

When estimated from the water balance (Fig. 5), *Dr* for treatments *A2* and *A3* differed statistically significant from the values for *A0* and *A1*, mainly in 2004; these differences, due to fertilizer doses and N uptake, were reflected in the variations in plant vigour observed in each plot. In the absence of water shortage or crop disease, greater vigour would infer higher evapotranspiration and lower drainage (Brisson et al., 1993). This is not the case; the *Kc* value applied was estimated on the grounds of the highest fertilizer doses that normally are applied. (*A3*). The differences in *Dr* began to be arise from 46th DAT, as indicated by the arrow in Fig. 4 showing the phenological stage of the crop and the *Kc*. These differences became more visible from the 67th DAT (Fig. 5) onward until the end of the crop cycle. At the same time, the widest gap between *ETc* and *Irr* was found in this period: see, for instance, irrigation on the 49st and 70th DAT (Fig. 5), which affected the *Dr* values. After

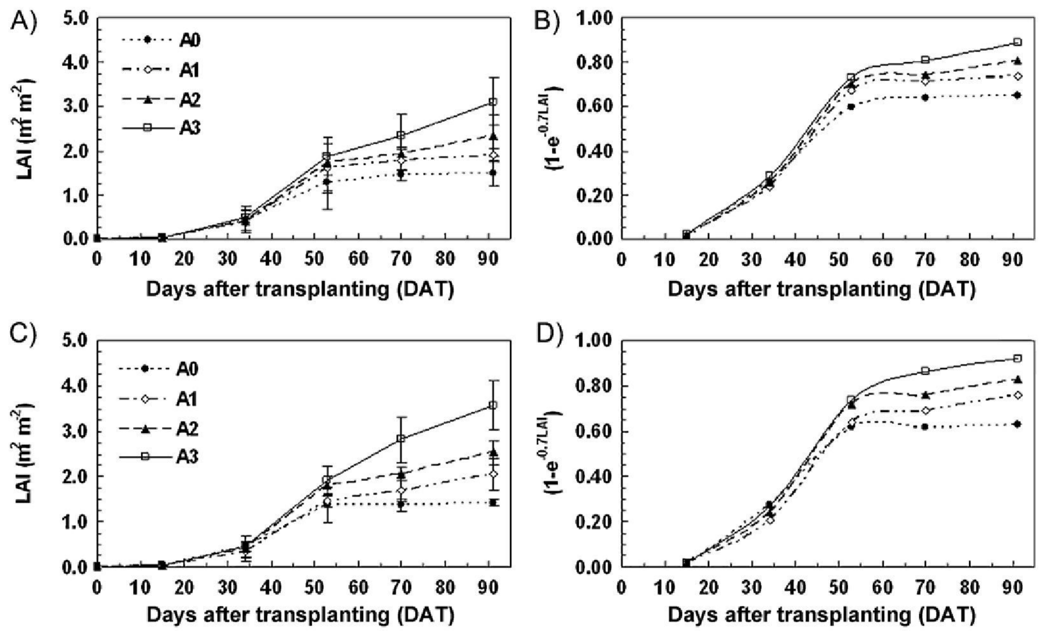

Fig. 6. Leaf area index (*LAI*) evolution through days after transplanting (*DAT*) for each fertilizer nitrogen treatment: 30 (*A0*), 85 (*A1*), 112 (*A2*) and 139 Kg N ha^{-1} (*A3*); (A) and (B) 2004, (C) and (D) 2005.

harvesting, the average *Dr* estimated for each treatment was, in mm: 100 ± 10 for *A0*, 89 ± 7 for *A1*, 67 ± 5 for *A2* and 62 ± 2 for *A3*.

The α can be calculated for each treatment and year, based on the *Dr* estimate (Eq. (6)), on the assumption that *Dr* for treatment *A3* primarily comprises the leach fraction. The *Ka* and α estimated for mid and final melon crop stages for both years, found with Eq. (8), are given in Table 3.

The α values found for treatments *A0*, *A1*, *A2* and *A3* between the 53rd and 91st DAT (arrows in Fig. 4, period I) were 0.82, 0.91, 0.98 and 1.0, for 2004 respectively, with $Kc = 0.90$ and 0.83, 0.90, 0.97 and 1.0, for 2005. Estimating the corresponding *ETa* in this period, a statistical significant difference between *A0* and *A3* is obtained in both years (around 43 mm). In the final phenological stage, from the 91st to the 105th DAT (period II in Fig. 4), the respective α values were 0.97, 0.97, 0.99 and 1.00 for 2004 and 0.99, 1.0, 1.0 and 1.0 for 2005. The corresponding *ETa* does not vary among the treatments being roughly 33 and 56 mm for each year.

In both years, α values were very similar in both periods (I and II). The effect of N treatment on α is higher on period I, as it was expected.

3.2. Evapotranspiration

The *LAI* estimates are plotted in Fig. 6A and C for 2004 and 2005 respectively. As expected, the mid-crop stage difference between treatments *A3* and *A0* was striking, beginning on the 50th or 53th DAT. The arrow in Fig. 5 marks that point as the beginning of the differences between treatments in terms of *LAI* and plant growth patterns with respect to cumulative *Dr*. Calculating transpiration for each treatment from Eq. (9) (Fig. 6B and D) revealed how it was affected by *LAI* between the 53th and 91st DAT.

The *Ka* and α values found with Eq. (10) for the mid-crop stage (Table 3) were observed to be very similar to the values estimated using *Dr* but never higher. Estimating the corresponding *ETa* in this period, a statistical significant difference between *A0* and *A3* is obtained again in both years (around 49 mm). Since the last *LAI* readings were taken at the 91st DAT, *Ka* could not be estimated since this date.

3.3. Plant growth

Average of both years on N uptake was not linear over time, with total amounts of 63.9 ± 11.0 (*A0*), 105.8 ± 8.29 (*A1*), 147.5 ± 23.18 (*A2*) and 156.3 ± 23.91 (*A3*) kg N ha^{-1}, as shown in Fig. 7A. The crop lowered the N pool in the soil in *A0* reference treatment plots only. The differences among treatments in N uptake began to appear on the 35th DAT, as indicated by the intersecting curves in Fig. 7B.

According to the graphs in Fig. 8A, N uptake and the increase in its *DW* are clearly related, while field tests revealed that the

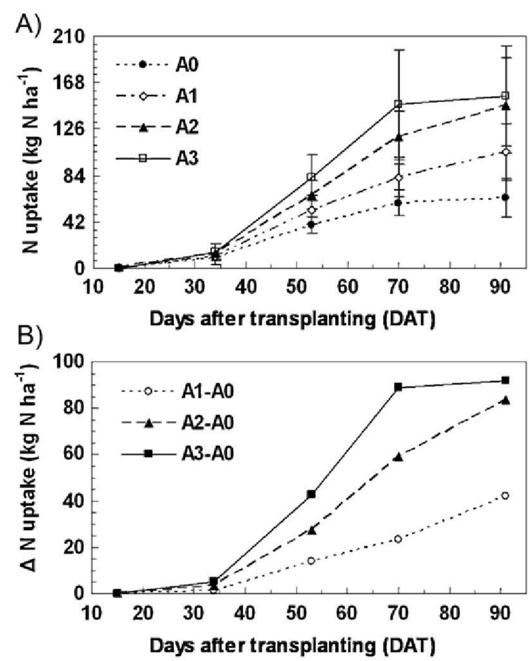

Fig. 7. Average N crop uptake between (2004 and 2005): (A) per treatment, (B) respect to *A0* treatment. Nitrogen doses are: 30 (*A0*), 85 (*A1*), 112 (*A2*) and 139 Kg N ha^{-1} (*A3*).

Table 3

Fertilizer factor (α) and coefficient adjusted through drainage estimation (*Ka*_1) and through leaf area index (*Ka*_2) for each treatment and at two different periods: (I) from 53 till 91 days after transplanting (DAT) and (II) from 91 till 105 DAT. The correspond adjusted evapotranspiration (*ETa*) is showed. Each fertilizer nitrogen treatment was: 30 (*A0*), 85 (*A1*), 112 (*A2*) and 139 kg N ha^{-1} (*A3*) in 2004 and 2005.

Treatment	*Ka*_1		α		*ETa* (mm)		*Ka*_2		α		*ETa* (mm)	
	I	II	I	II	I	II	I	II	I	II	I	II
	2004											
A0	0.74	0.68	0.82	0.97	200	33	0.72	–	0.80	–	194	–
A1	0.82	0.68	0.91	0.97	221	33	0.80	–	0.90	–	216	–
A2	0.88	0.69	0.98	0.99	238	33	0.84	–	0.93	–	227	–
A3	0.90	0.70	1.00	1.00	243	34	0.90	0.70	1.00	1.00	243	34
	2005											
A0	0.75	0.69	0.83	0.99	210	55	0.74	–	0.82	–	207	–
A1	0.81	0.70	0.90	1.00	227	56	0.81	–	0.90	–	227	–
A2	0.87	0.70	0.97	1.00	244	56	0.86	–	0.95	–	241	–
A3	0.90	0.70	1.00	1.00	252	56	0.90	0.70	1.00	1.00	252	56

treatments with higher N doses, *A2* and *A3*, exhibited greater plant vigour.

Similar patterns were observed when the differences in DW (Fig. 8B) with respect to treatment *A0* were plotted against DAT. DW versus crop N uptake with respect to *A0* could be fitted to logarithmic curve (Fig. 9), with R^2 values of 0.84. Consequently, this constitutes a solid correlation that can be used to quantify *DW* increases when N uptake is enhanced with fertilizers having higher N content than reference treatment *A0*.

The N affected the *FY* in all 2 years. The highest *FY* was obtained with *A2*, decreasing by 18 and 12% in relation to the *A0* and *A3*, respectively. A second-order polynomial curve was found by relating the *FY* to N: $y = -0.00004x^2 + 0.0075x + 0.6274$; $R^2 = 0.79$; $p \leq 0.05$. According to the equation, the maximum *FY* was obtained with N applied of 94 kg ha^{-1} and, above this amount, N had a negative effect on yield.

It is known that as the N rate increases so does fruit yield up to a maximum value beyond which any increase in N rates leads to a corresponding yield decrease (Purqueiro et al., 2003; Kirnak et al., 2005).

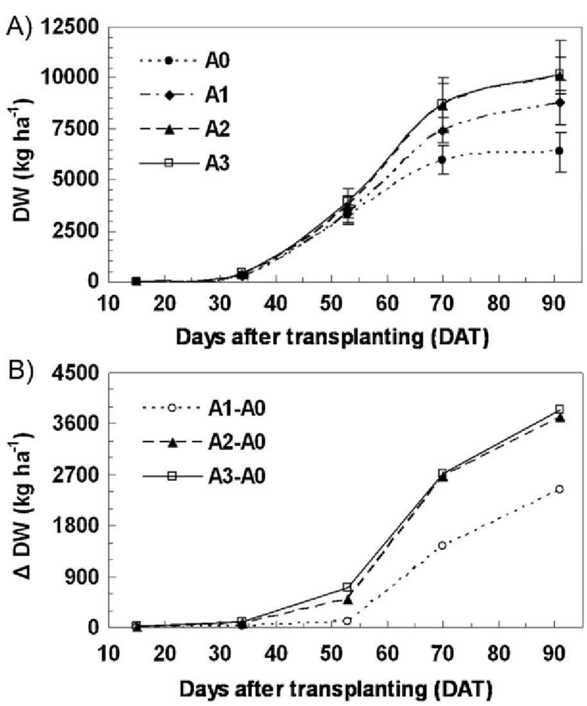

Fig. 8. Average growth curves in dry weight (*DW*) (2004 and 2005): (A) per treatment, (B) respect to *A0* treatment. Nitrogen doses are: 30 (*A0*), 85 (*A1*), 112 (*A2*) and 139 kg N ha^{-1} (*A3*).

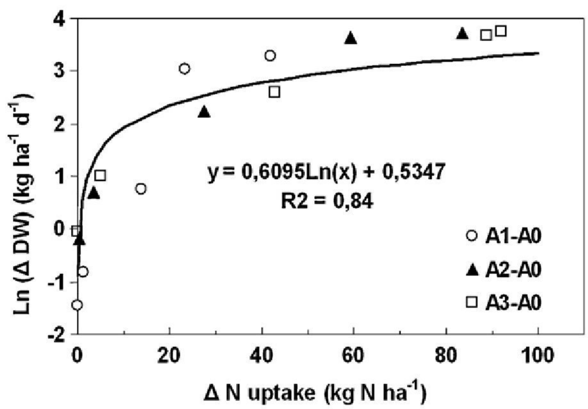

Fig. 9. Relation between increments in N uptake by the plant (ΔN uptake) and increments in plant growth expressed as dry weight (Δ*DW*).

4. Conclusions

Good irrigation practice entails determining optimal water and fertilizer requirements and establishing the proper timing for both. Crop water requirements (*ETc*) were determined previously for this area using a melon crop coefficient (*Kc*) based on N doses used by local farmers. The use of different N doses yields different evapotranspiration values (*ETa*) due to the concomitant differences in plant growth impacting crop transpiration.

No significant differences were observed among the various treatments in terms of *Dr* until the 50th DAT; from that time onward, and water losses were more intense in the low dose treatments than the highest one. The greater nitrogen uptake was used by plants to enhance vegetative growth and *LAI* showing that this difference is close to the differences observed in the drainage.

ETa values were obtained multiplying *Kc* by a coefficient (α) that was estimated from the differences of the accumulated *Dr* or from *LAI* growth rates ratio with respect to the maximum N dose used as it is the usual one applied in the area. The former method can be applied during all the crop cycle meanwhile the last one is not applicable during the senescent period. The difference between *ETa* in both years depending on the *Ka* applied could achieve 42–49 mm at vegetative period and it is not significant at senescent period. Such adjustments are crucial considering that soil depth in the area is only 0.60 m and that the crop water use requirements during the cycle are quite high.

Acknowledgements

This work was funded by the Spanish National Institute for Agricultural and Food Research and Technology (Spanish initials, INIA) under Project INIA RTA 04–111–C3 and INIA RTA 2010-00110-CO3. The last author has been partially funded by Spanish Ministerio de Ciencia e Innovación (MICINN) through Project AGL2010-21501/AGR.

References

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 2002. Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. Irrigation and drainage paper no. 56. 3rd ed., FAO, Rome.

Association of Official Analytical Chemists (AOAC), 1990. Official Methods of Analysis, In: Helrich, K. (Ed), AOAC, Arlington, VA.

Ayers, R.S., Westcott, D.W., 1985. Water Quality for Agriculture. FAO irrigation and drainage paper no. 29, FAO, Rome.

Bawatharani, T., Mowjood, M.I.M., Dayawansa, N.D.K., Kumaragamage, D., 2004. Nitrate leaching as a function of fertilization and irrigation practices in sandy regosols. Tropical Agricultural Research 16, 172–180.

Bilbao, M., Martínez, J.J., Delgado, A., 2004. Evaluation of soil nitrate as a predictor of nitrogen requirement for sugar beet grown in a Mediterranean climate. Agronomy Journal 96, 18–25.

Brisson, N., Olioso, A., Clastre, P., 1993. Daily transpiration of field soybeans as related to hydraulic conductance, root distribution, soil potential and midday leaf potential. Plant Soil 154 (2), 227–237.

Brown, P.W., Mancino, C.F., Young, M.H., Thompson, T.L., Wierenga, P.J., Kopec, D.M., 2001. Penman Monteith crop coefficients for use with desert turf systems. Crop Science 41, 1197–1206.

Cartagena, M.C., Vallejo, A., Diez, J.A., Bustos, A., Caballero, R., Román, R., 1995. Effect of type of fertilizer and source of irrigation water on N use in a corn crop. Field Crops Research 44, 33–39.

Casey, F.X.M., Derby, N., Knighton, R.E., Steele, E.C., 2002. Initiation of irrigation effects on temporal nitrate leaching. Vadose Zone Journal 1, 300–309.

Castellanos, M.T., Cartagena, M.C., Ribas, F., Cabello, M.J., Arce, A., Tarquis, A.M., 2007. Medidas en campo del balance de agua y de nitrógeno en un cultivo de melón con fertirrigación. In: Giradles, J.V., Jiménez, F.J. (Eds.), Estudios de la Zona no Saturada del Suelo, Vol. VIII, 217–223.

Castellanos, M.T., Cartagena, M.C., Ribas, F., Cabello, M.J., Arce, A., Tarquis, A.M., 2010. Efficiency indexes for melon crop optimization. Agronomy Journal 102, 716–722.

Chartzoulakis, K.S., 1994. Photosynthesis, water relations and leaf growth of cucumber exposed to salt stress. Scientia Horticulturae 59, 27–35.

Derby, N.E., Steele, D.D., Terpstra, J., Knighton, R.E., Casey, F.X.M., 2005. Interactions of nitrogen, weather, soil and irrigation on corn yield. Agronomy Journal 97, 1342–1351.

Doorenbos, J., Pruitt, W.O., 1977. Crop Water Requirements. Irrigation and drainage paper no. 24, FAO, Rome.

Doorenbos, J., Kassam, A.H., 1988. Yield Response to Water. Irrigation and drainage paper no. 33, FAO, Rome.

Eilers, V.H.M., Carter, R.C., Rushton, K.R., 2007. A single layer soil water balance model for estimating deep drainage (potential recharge): an application to cropped and in semi-arid North-east Nigeria. Geoderma 140, 119–131.

Fagade, S.O., De Datta, S.K., 1971. Leaf area index, tillering capacity, and grain yield of tropical rice as affected by plant density and nitrogen level. Agronomy Journal 63, 503–506.

Flesch, T.K., Dale, R.F., 1988. Nitrogen argument for corn leaf area models. Agronomy Journal 80, 784–789.

Flores, P., Castellar, I., Navarro, J., 2005. Nitrate leaching in pepper cultivation with organic manure and supplementary additions of mineral fertilizer. Soil Science and Plant Analysis 36, 2889–2898.

Khalifa, M.A., 1973. Effects of nitrogen on leaf area index, leaf area duration, net assimilation rate, and yield of wheat. Agronomy Journal 65, 253–256.

Kirnak, H., Higos, D., Kaya, C., Tas, I., 2005. Effects of irrigation and nitrogen rates on growth, yield, and quality of muskmelon in semiarid regions. Journal of Plant Nutrition 28, 621–638.

Lovelli, S., Pizza, S., Caponio, T., Rivelli, A.R., Perniola, M., 2005. Lysimetric determination of muskmelon crop coefficients cultivated under plastic mulches. Agricultural and Water Management 72, 147–159.

M.A.R.M., 2009. http://www.mapa.es/estadistica/pags/anuario/2009/Anuario2009.pdf

Miller, R.J., Langdale, G.W., Myhre, D.L., 1967. Leaf area indices and nitrogen uptake of flue-cured tobacco as affected by plant density and nitrogen rate. Agronomy Journal 59, 409–412.

Miner-Moptma, 1994. White Paper of Groundwater. MOPTMA, Madrid (Libro Blanco de las aguas subterráneas).

Moreno, F., Cayuela, J.A., Fernández, J.E., Fernández-Boy, E., Murillo, J.M., Cabrera, F., 1996. Water balance and nitrate leaching in an irrigated maize crop in SW Spain. Agricultural and Water Management 32, 71–83.

Nakamura, K., Harter, T., Hirono, Y., Horino, H., Mitsuno, T., 2004. Assessment of root zone nitrogen leaching as affected by irrigation and nutrient management practices. Vadose Zone Journal 3, 1353–1366.

Niaz, A., Ibrahim, M., Nadeem, M.Y., Saneen, A., Ahmed, W., Katar, F.M.Z., 2004. Nitrate leaching losses under different irrigation frequencies and uptake in cereal foods. Journal of Agricultural Science 41 (3–4), 95–101.

Oenema, O., van Liereb, L., Schoumansa, O., 2005. Effects of lowering nitrogen and phosphorus surpluses in agriculture on the quality of groundwater and surface water in the Netherlands. Journal of Hydrology 304, 289–301.

Ortega, J.F., De Juan, J.A., Tarjuelo, J.M., 2003. Evaluación y análisis del funcionamiento del riego localizado en cultivos hortícolas de Castilla-La Mancha. In: Actas de Horticultura No. 39, X Congreso Nacional de Ciencias Hortícolas, Pontevedra, 61–63.

Poch, R., Mailhol, J.C., Candela, L., Ramírez, F., 2005. Estimación de los riesgos de lixiviación de nitratos en suelos agrícolas: ¿Enfoque numérico o funcional? In: Estudios de la Zona No Saturada del Suelo, Vol. VII, 177–184.

Purqueiro, L.F.V., Cecílio Filho, A.B., Barbosa, J.C., 2003. Effect of nitrogen concentration in nutrient solution and number of fruits per plant on yield of melon. Horticultura Brasileira 21 (2), 185–190.

Ribas, F., Cabello, M.J., Moreno, M.M., 1995. Necesidades de riego del melón y respuesta del cultivo a riegos diferenciales en la provincia de Ciudad Real (Castilla-La Mancha). In: XIII Jornadas Técnicas sobre Riegos, Tenerife, 12–20.

Rincón, L., 1997. Fertilización del melón en riego por goteo. In: Melones 10, Ediciones de Horticultura, Barcelona, 86–94.

Rincón, L., Giménez, M., 1989. Fertirrigación por goteo en melón. Fert 105, 55–56.

Sainz Rozas, H.R., Echeverría, H.E., Studdert, G.A., Andrade, F.H., 1999. No-tillage corn nitrogen uptake and yield: effect of urease inhibitor and application time. Agronomy Journal 91, 950–955.

Sainz Rozas, H.R., Echeverria, H.E., Picone, L.I., 2001. Denitrification in maize under no-tillage: effect of nitrogen rate and application time. Soil Science Society of America Journal 65, 1314–1323.

Selamat, A., Gardner, F.P., 1985. Growth, nitrogen uptake, and partitioning in nitrogen-fertilized nodulating and nonnodulating peanut. Agronomy Journal 77, 862–867.

Soil Survey Staff, 2010. Keys to Soil Taxonomy. 11th ed. USDA-Natural Resources Conservation Service, U.S. Gov. Printing Office, Washington, USA.